CHAPTER III

ATOMIC LINE SPECTRA

3.1 <u>Wave-Particle Duality</u>

Early in the twentieth century, there was a debate about whether light was composed of particles or waves. Most commonly observed phenomena goes with light is electromagnetic waves. However, the blackbody radiation, x-rays, photoelectric effect, and atomic line spectra suggest a particle nature for light, photon theory.

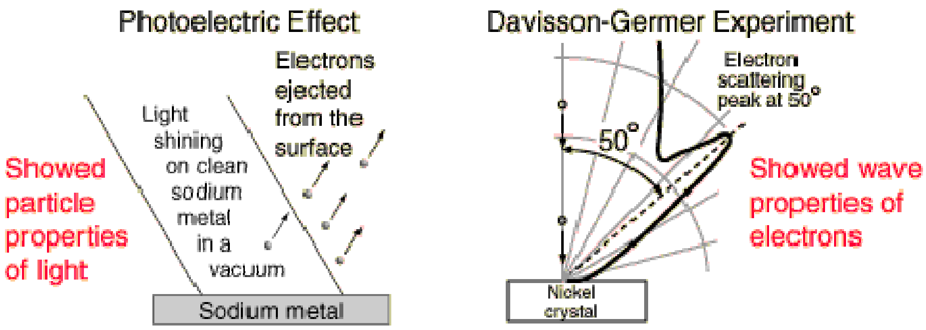


Fig. (3.1)

The wave-particle duality for light and electrons

A wave-particle dual nature soon is characteristic of electrons as well. The evidence for the description of light as waves was well established when the *photoelectric effect* introduced firm evidence of a particle nature as well. On the other hand, the particle properties of electrons were well documented when the *DeBroglie hypothesis* and the subsequent experiments by *Davisson and Germer* established the *wave nature* of the electron.

The frequency available is continuous and has no upper or lower bound, so there is no finite lower limit or upper limit on the possible energy of a photon, the light quantum particle. On the upper side, there are practical limits because you have

limited mechanisms for creating really high energy photons. Low energy photons are bound, but when you get below radio frequencies, the photon energies are so tiny compared to room temperature thermal energy, they are never sensed as distinct quantized entities, they are swamped in the background. Another way to say this, is that in the low frequency limits, things just blend in with the classical treatment of things and a quantum treatment is not necessary.

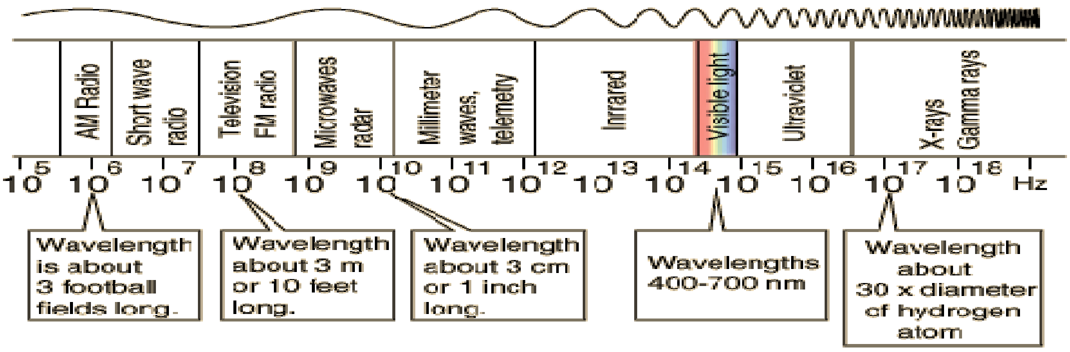


Fig.(3.2)
The electromagnetic waves spectrum

The *Photoelectric Effect* occurs when light falls on a metallic plate, electrons are emitted from it. This metal plate is called the emitter. The emitted electrons are collected at another plate called the collector. Both electrodes are connected to an outer circuit in forward or reverse bias as shown in fig.(3.3).

As soon as the incident light strikes the emitter, the photocurrent begins. The photocurrent is instantaneous and directly proportional to the intensity of the incident light beam, I_0. The potential difference between the emitter and the collector, V, is varied and the resulting photoelectric current, $\boldsymbol{i}$, has two main characteristics:

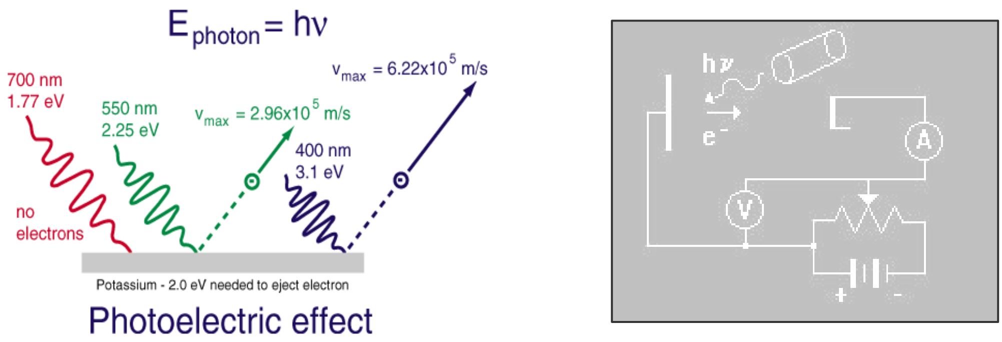


Fig. (3.3)
The photoelectric effect and photodiode

i. ***i*** is proportional with the incident light intensity I_0

ii. ***i*** is equal to zero for incident light with frequency less than the threshold frequency, ν_0 , even for the most intense beams of light.

Classical theory would conclude that the emitted electrons must acquire their kinetic energy from the light beam. Hence increasing the intensity of the light beam would emit photoelectrons with higher energy values. The energy of the emitted electrons is independent of the light intensity whereas the photocurrent is, as the number of incident photons per second increase.

If the applied voltage is reversed and increased in the reverse bias till ***i*** is zero; collector is negative while the emitter is positive. The potential is hence known as the stopping potential, V_s. The total energy possessed by the electrons, in case of their stopping on the emitter, is thus the maximum potential energyis given as: $P.E_{max} = e\,V_s$.

For a constant frequency ν and light intensity I_0, the photocurrent, ***i,*** decreases with increasing the retarding potential. V_s depends on the frequency of the light, but is independent of the light intensity and therefore is independent of the photocurrent. The V- ***i*** characteristic of the photodiode is shown in fig.(3.4), for two light intensities. It is

obvious that higher intensities cause higher saturation current and vice versa. On the other hand both incident intensities give the same stopping potential.

3.1.1.<u>Classical interpretation Failure</u>:

Based on classical properties of electromagnetic waves the following statements must be justified:

1-The absorbed energy is proportional to the intensity of light, the area illuminated, and the time of illumination. This means that at lower light intensities we must wait more time until photo current is emitted which doesn't happen, as delay measured never exceeded 10^{-9} second.

2-V_s does not depend on intensity which mean that the maximum kinetic energy, is independent on the total energy absorbed by the surface as shown in fig.(3.4).

3- The existence of threshold frequency, ν_0, for a given metal is completely unexplainable on classical basis. Fig.(3.5) shows that ν_0 of sodium is $4.39*10^{14}$ Hz Likewise, the dependence of the stopping potential on the frequency is unexplained.

3.1.2 <u>Early Photoelectric Effect Data</u>

Analysis of data from the *photoelectric experiment* showed that the energy of the ejected electrons was proportional to the frequency of the illuminating light. This showed that whatever was knocking the electrons out had an energy proportional to light frequency. The remarkable fact that the ejection energy was independent of the total energy of illumination showed that the interaction must be like that of a particle which gave all of its energy to the electron! This fits in well with *Planck's hypothesis* that light in the *blackbody radiation* experiment could exist only in discrete bundles with energy, ($E = h\nu$).

The details of the photoelectric effect were in direct contradiction to the expectations of very well developed classical physics concepts. The explanation marked one of the major steps toward quantum theory.

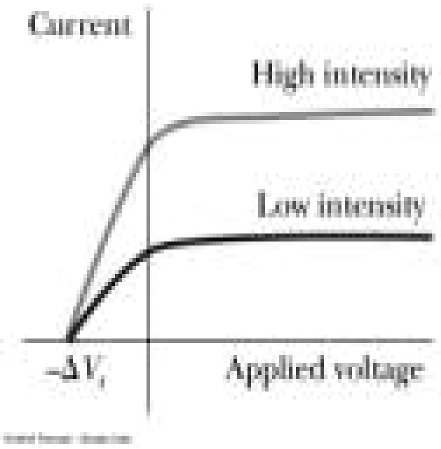


Fig.(3.4)

The V-*i* characteristic of the photodiode

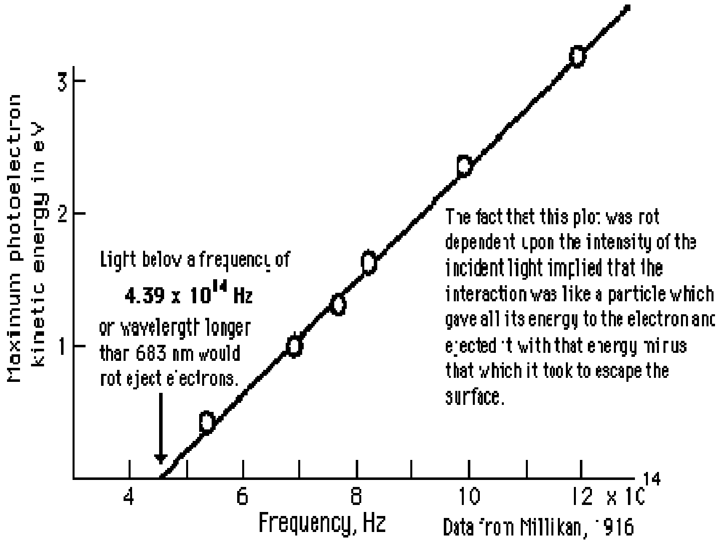


Fig.(3.5): The K.E.$_{max}$ sketched against incident light frequency for sodium metal

The aspects of the photoelectric effect that contradict classical analysis are:

1. The electrons were emitted immediately - no time lag!
2. Increasing the intensity of the light increases the number of photoelectrons but not their maximum kinetic energy!
3. Red light will not cause the ejection of electrons from a potassium surface, no matter what the intensity!
4. A low intensity violet light will eject only a few electrons, but their maximum kinetic energies are greater than those for intense light of longer wavelengths.

Electrons ejected from a sodium metal surface are measured as an *electric current*. Finding the opposing *voltage* it took to stop all the electrons, V_s , gave a measure of the maximum *kinetic energy* of the electrons in eV_s.

$$K.E._{max} = e\,V_s \qquad \ldots\ldots(3.1)$$

Fig.(3.5) shows the relation of eV_s against frequency. The minimum energy required to eject an electron from the surface is called the photoelectric work function. The threshold for this element corresponds to a wavelength of 683 nm as shown in fig.(3.5). Using this wavelength in Einestien's equation, eq.3.3, the photon energy is equal to 1.82 eV. This energy is defined as the work function of sodium, φ_{Na}.

3.1.3. Quantum Explanation:

According to the Planck hypothesis, all electromagnetic radiation is quantized and occurs in finite "bundles" of energy which we call photons. The quantum of energy for a photon is not Planck's constant ***h*** itself, but the product of ***h*** and the frequency. The quantization implies that a photon of blue light of given frequency or wavelength will always have the same size quantum of energy. For example, a photon of blue light of wavelength 450 nm will always have 2.76 eV of energy. It occurs in quantized chunks of 2.76 eV, and you can't have half a photon of blue light - it always occurs in precisely the same sized energy chunks.

1- Photo-emission occurs with no delay, because it does not take time to hit the electron by the photon and release an electron; energy transfer takes place instantaneously.

2- Increase in the intensity means increasing the number of photons striking the metal surface and so the number of photoelectrons liberated increases, and accordingly the current increases.

3- Since the energy of the photon and the work function are well defined, a well defined maximum kinetic energy of the photoelectrons exists for a given frequency. As a result, a well defined stopping potential exists regardless of the intensity of the incident radiation.

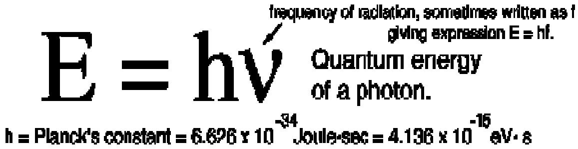
4- The work function, φ, is also well defined for a particular metal. If the energy of the photon is less than φ, no photocurrent emerges and so the minimum energy for a photon to liberate an electron from a metallic surface is $h\nu_0$, hence,

$$\varphi = h\nu_0$$

$$\lambda_0 = c/\nu_0 = hc/\varphi \qquad \ldots\ldots(3.2)$$

3.2 Relations and graphs:

Albert Einstein (1905) showed that the experimental results are explained by what is known as Einestein's Equation :



…….(3.3)

For forward bias photodiode energy equation per electron is:

$$\boldsymbol{KE_{max} = h\nu - \varphi} \qquad \boldsymbol{KE_{max} = h\nu - h\nu_0} \qquad \text{…….(3.4)}$$

For reverse bias photodiode energy equation per electron is:

$$\boldsymbol{eV_s = h(\nu - \nu_0) = hc(1/\lambda - 1/\lambda_0)} \qquad \text{…….(3.5)}$$

where KE_{max} is the maximum kinetic energy possessed by the photoelectrons, ν_0 is the threshold frequency and φ is the work function of the metal or the minimum energy needed to free an electron from its metal surface.

Knowing the work function for different materials we can plot the following figures, fig.(3.6) for different metallic surfaces. The slopes of these graphs is always constant and equal to Planck's constant, h, which gives it more validity and allowed Einestein to announce firmly his equation.

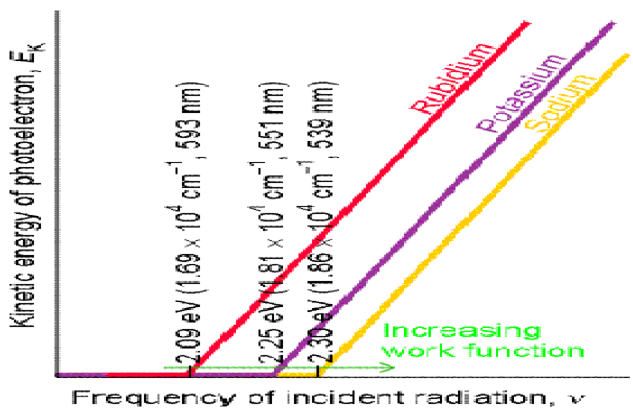


Fig.(3.6)

Max KE against frequency for different metals

<u>Example 3.1:</u>

What is the maximum kinetic energy and speed of an electron ejected from a calcium surface whose work function is φ=2.9 eV when illuminated by a light of wavelength a) 410 nm b) 550 nm ?

Solution :
For calcium
a) λ=410nm, $h\nu=hc/\lambda$ =1240/410=3.03eV
$K.E_{max}$ =3.03-2.9=0.13eV ,
$v=\sqrt{2} *0.13*1.6*10^{-19}/9.1*10^{-31)}$ = m/s

b) λ=550nm, $h\nu=hc/\lambda$ =1240/550=2.25eV

$K.E_{max}$ =0 , v=0 $\rightarrow$ No emission as $h\nu \lt \varphi$.

3.3 X-Rays:

An x-ray machine, like that used in a doctor's or a dentist's office, is very simple. Inside the machine is an x-ray tube. An electron gun inside the tube shoots high energy electrons at a target made of heavy atoms, such as **tungsten** X-rays come out because of atomic processes caused by energetic electrons shot at the target.

3.3.1. Apparatus:

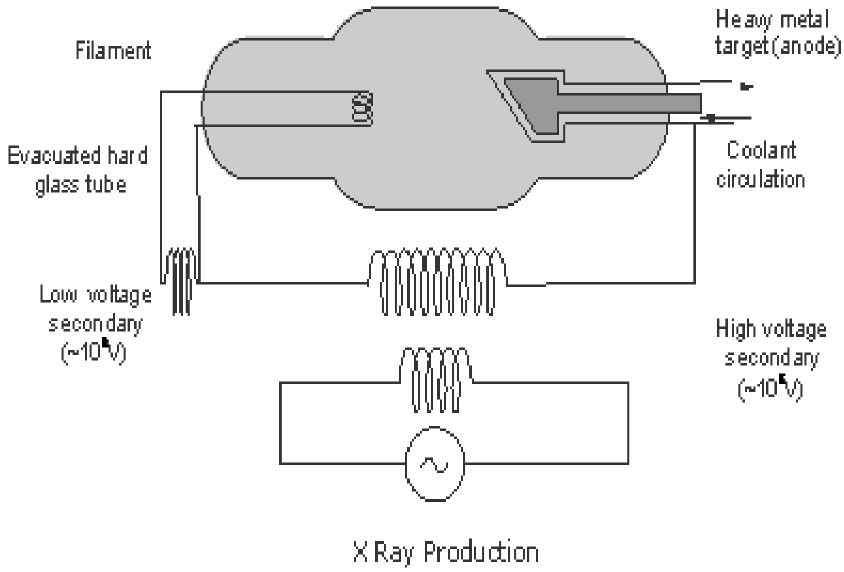


Fig.(3.7)

3.3.2 X-Ray production

X-rays are just like any other kind of electromagnetic radiation. They can be produced in parcels of energy called photons, just like light with shorter wavelengths

and higher frequencies of range (10^{17}-10^{19})Hz. Two different atomic processes can produce x-ray photons. One is called, **Bremsstrahlung**, which is a German name meaning "braking radiation." The other is called **K-shell emission**. They can both occur in heavy atoms like tungsten. Both ways of making x-rays involve a change in the state of electrons. Bremsstrahlung is easier to understand using the classical idea that radiation is emitted when the velocity of the electron shot at the tungsten changes. This electron slows down after swinging around the nucleus of a tungsten atom and loses energy by radiating x-rays. In the quantum picture, many photons of different wavelengths are produced, but none of the photons has more energy than the electron. After emitting the spectrum of x-ray radiation the original electron is slowed down or stopped.

3.3.3 "K-shell" x-rays

Atoms have their electrons arranged in closed "shells" of different energies. The K-shell corresponds the lowest energy state of an atom. The incoming electron from the electron gun can give a K-shell electron in a tungsten target atom enough energy to knock it out of its energy state. Then, a tungsten electron of higher energy state, from an outer shell, can fall into the K-shell to fill its space. The energy lost by the falling electron is released as an emitted x-ray photon. Meanwhile, higher energy electrons fall into the vacated energy state in the outer shell, and so on.

K-shell emission produces higher-intensity x-rays than Bremsstrahlung, and the x-ray photon comes out at a single wavelength.

3.3.4 The X-Ray spectrum

The highest frequency of electromagnetic wave released in this manner is that resulting from the greatest loss of kinetic energy in a single collision with a target atom. Therefore,

$$h\nu_{max} = eV_{dc} \qquad \ldots\ldots(3.6)$$

Lower frequencies are released when the decelerating electrons make multiple collisions losing energy in stages.

Thus the minimum wavelength λ_{min} emitted by the X-ray tube is given by:

$$hc/\lambda_{min} = eV_{dc} \qquad …….(3.7)$$

Spikes in the curve:

In addition to this background radiation, there are also some pronounced spikes seen in the sketch graph of the emission spectrum of X rays shown in fig.(3.8). These are called the *CHARACTERISTIC LINES* and are generated from re-radiation after excitation of orbiting electrons from lower to higher permitted shells in atoms of the target material. The reason for those peaks was unknown until Bohr postulated that electrons inside atoms have quantized energy states. Inside a metal, the inner shell electrons are tightly bound to their own nuclei and thus have quantized energy states. If the X-ray tube voltage is high enough, an incident electron may collide with one of those inner shell electrons, transferring it to a higher energy state. An electron from another higher energy state quickly fills in the vacancy by emitting a photon. It turns out that there is a very large probability for certain transitions and thus we find a very high intensity of emitted radiation at particular wavelengths ($K_{\alpha,}$ K_{β}).

Why does the innermost electron while one may guess the outermost electron would be the easiest to knock out?

An x-ray photon has a lot of energy in it, and only transitions of the inner electrons release that much energy. Transitions of the outer electrons, which can happen, might be in the infrared or visible part of the spectrum. For the electron energies used in x-ray tubes, it turns out the inner electrons are the most likely to be knocked out so that $L\alpha$ & $L\beta$ show low intensity on the spectrum.

The above discussion is summarized in fig.(3.8).

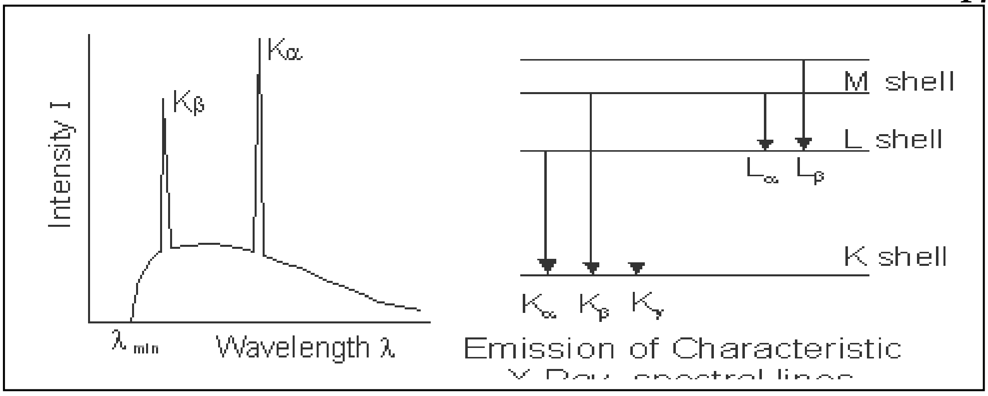
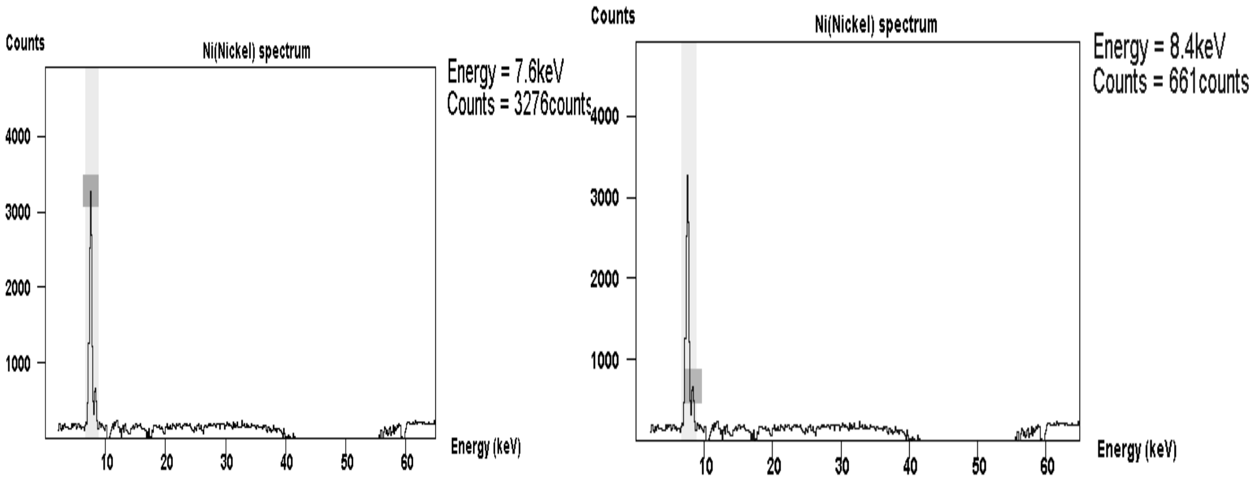


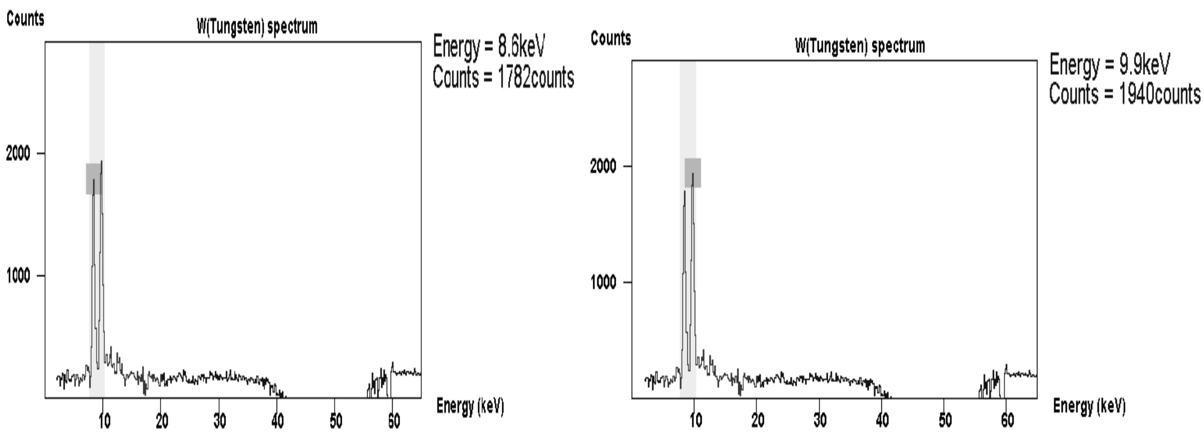
Fig (3.8) k_α is radiated when line results from a change involving the L shell and the K_β is radiated when the change involving the M shell and so on.

Examples of X-Ray spectrum for different materials:



$k_{\alpha 1}$=hc /E=0.1634nm $k_{\beta 2}$=hc /E=0.1479nm

Fig.(3.9.a) The x-ray spectrum for Nickel



$k_{\alpha 1}$=0.1444nm $k_{\beta 2}$=0.125nm

Fig.(3.9.b) The x-ray spectrum for Tungesten

The following table illustrates different wavelengths at which x-ray radiation for different metallic targets from spectra as shown in fig.(3.9):

Target	K_{β_1}	K_{β_2}	K_{α_1}	K_{α_2}
Fe	0.17566	0.17442	0.193604	0.193998
Ni	0.15001	0.14886	0.165791	0.166175
Cu	0.139222	0.138109	0.154056	0.154439
Zr	0.070173	0.068993	0.078593	0.079015
Mo	0.063229	0.062099	0.070930	0.071359

Table.3.1 Different wavelengths of x-ray radiation

Note that as energy states differ for different target materials, so the generated photons will have different frequencies for each metallic target as shown in table 3.1. This means that the generated x-ray wavelengths are characteristic of the target material.

3.3.5. <u>Increase in the accelerating voltage:</u>

Increase of the accelerating voltage applied, V_{dc}, between filament and target is found to increase the penetrating power of the x-rays. Since the maximum loss of kinetic energy at a single collision is now higher, the highest frequency emitted is also higher as expected. Thus the quality of the emitted X rays is altered. These are called ‘hard’ x-rays.

3.3.6. <u>X-ray dose measurement:</u>

To measure x-ray intensity, the scintillation counter is preferable. It gives a reading in the form of n, counts/sec, corresponding to the number of incident photons per sec. n photons/sec possess a total energy/sec of E_t (j/s)

$$E_t = n\,h\,\nu \qquad \ldots\ldots\ (3.8)$$

This energy causes a total dose equal of E_t multiplied by the time during which the person is subjected to the radiation. It is then produced in rads.

3.4 <u>Atomic Electromagnetic Spectrum:</u>

When a a discharge tube is filled with a low-pressure gas then excited by applying a high voltage, the gas glows. The emitted radiation, analyzed by a diffraction grating or a prism, is resolved into different spectral lines. The important issue is that each particular gas shows a different spectrum. The gas spectral lines are unique and discrete as shown in fig. (3.10-3.11). The characteristic spectral lines act like a fingerprint that can be used to identify the gas. This spectrum is quiet different from the continuous spectrum of the sun electromagnetic radiation or from continuous light spectrum, emitting a rainbow of colors. White light has a continuous spectrum and all wavelengths of the visible range, (400-750)nm, are obtained.

The sun has not much different Fig. (3.11.a), a continuous spectrum with Franhofer lines, which appear as dark lines on the spectrum. The spectrum of the sun is obtained by photographing a slit in the window blind with a similar grating set-up. These lines signify that some wavelengths are missing. The dark lines are absorbed wavelengths from the continuous spectrum which indicate the presence of some gases that absorb these specific wavelengths.

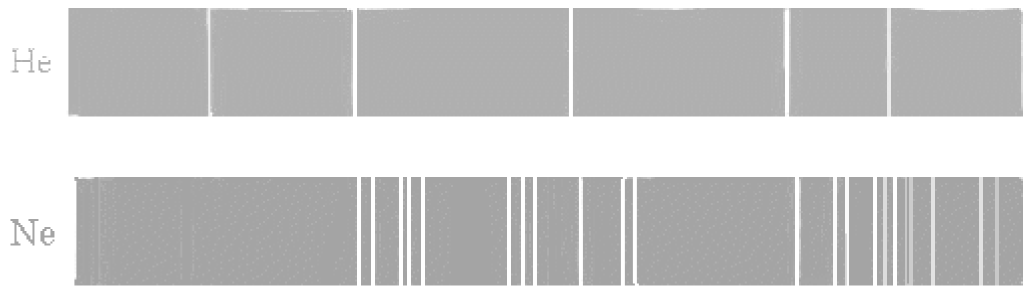


Fig.(3.10)
Different emission wavelengths from discharge tubes for He and Ne gases

COMPARISON BETWEEN THE EMISSION SPECTRUM OF HYDROGEN AND SPECTRUM OF THE SUN:

In Fig. (3.11.b), the spectrum of a glass tube filled with hydrogen that is excited with a high voltage shows the red line at the left, the blue-green line in the right center, and

the violet line is the second from the right. On the extreme right is an ultraviolet line that human eyes cannot see, but is barely detectable by a digital camera. The visible lines in the hydrogen spectrum are called the Balmer lines of hydrogen. Some dark lines, Franhofer lines, on the sun spectrum are coincident with the bright lines of the hydrogen. Notice that there are several other dark lines for elements other than hydrogen. Helium gas, that surrounds the sun causing a part of the absorption spectrum, was discovered on the sun before it was discovered on earth. The dark lines are called absorption lines, they are characteristic of all stars, and are caused by absorption of light by the elements in their atmospheres.

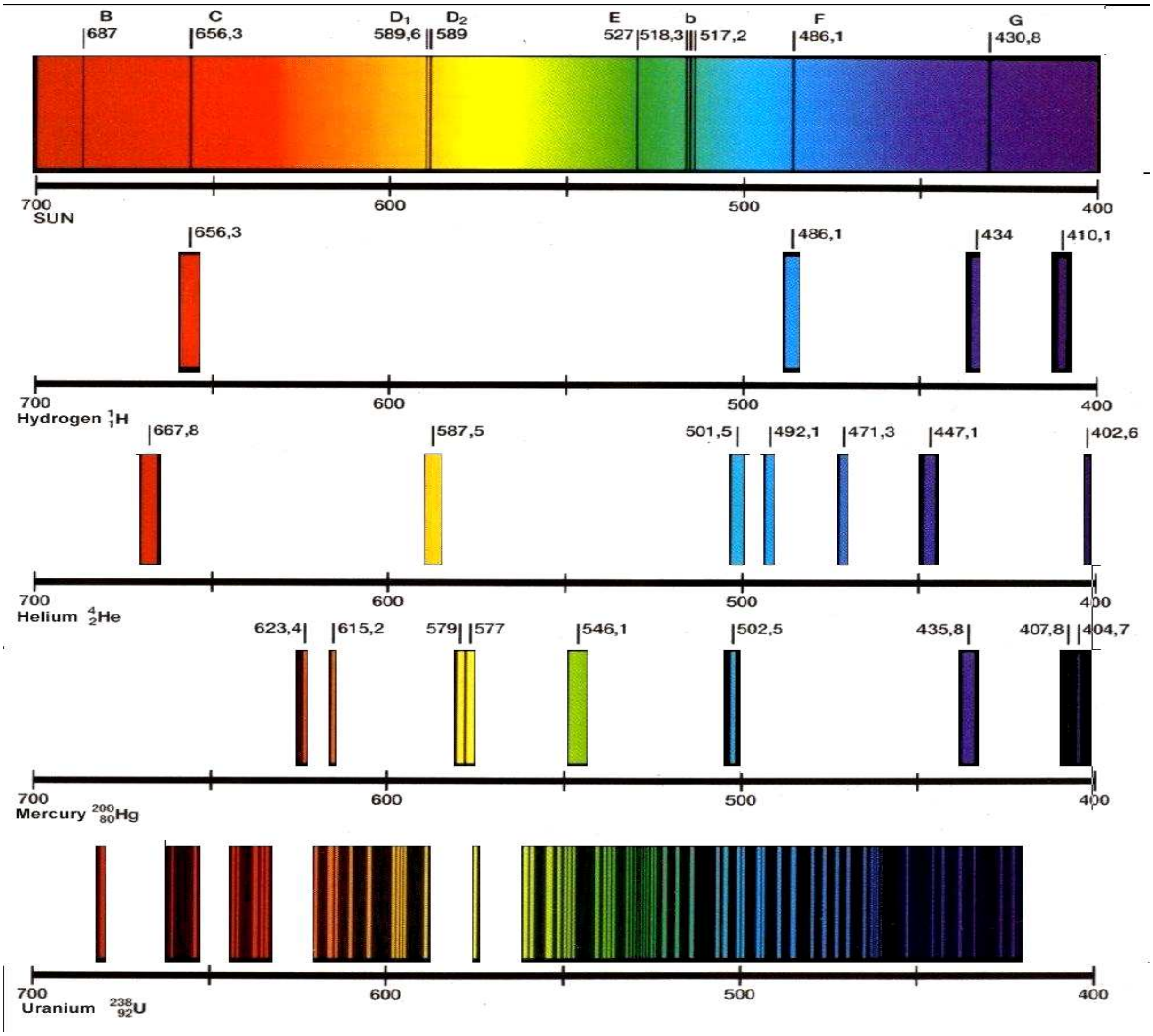


Fig (3.11)

Sets of spectral lines in nm emitted by a particular gas when excited

Accordingly, one can define the emission spectrum as the characteristic set of spectral lines emitted by a particular gas when excited. The absorption spectrum is the set of spectral lines that are absorbed by a gas when a continuous spectrum passes through it. These absorbed lines appear dark on the rainbow background and correspond exactly to some lines in the absorption spectrum and are known as the gas fingerprints.

3.5. Atomic models:

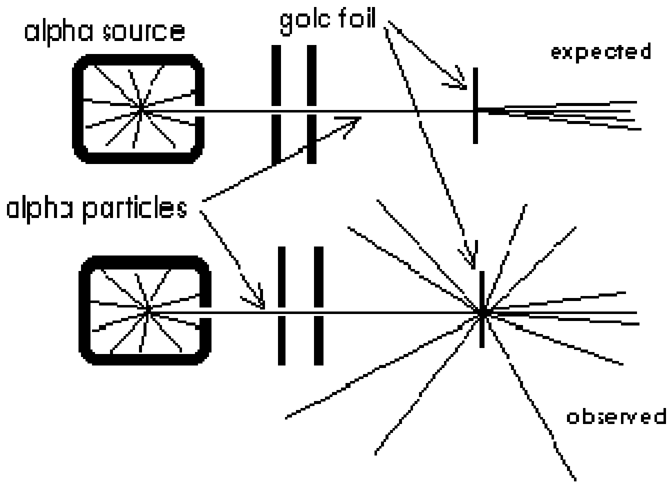


Fig (3.12)

Sets of spectral lines emitted by a particular gas when excited

3.5.1. Rutherford model of the atom:

A great deal of information about the internal structure of objects is obtained from scattering experiments. Rutherford and his collaborates carried out a particle scattering experiment. A beam of α particles is directed towards a thin foil of gold. The scattered particles were detected carefully at all the expected angles as shown in fig.(3.12). From these experiments, it was deduced that the atom consists of a nucleus of 10^{-14} m surrounded by a relatively huge void.

Electrons orbit around the atom at a radius of the order of 10^{-10} m.

Rutherford's atomic model is known as the planetary model for the hydrogen atom. The electron rotates around the proton the same way as the earth around the sun. The

force, F, is the electrostatic force of attraction between the electron and the single proton of the nucleus.

$$F = \frac{e^2}{4\pi\varepsilon_0 r^2} \qquad \ldots\ldots(3.9)$$

For the electron to rotate in a circular motion, the force of attraction must be equalized to a centripetal force such that:

$$\frac{e^2}{4\pi\varepsilon_0 r^2} = m\frac{v^2}{r}$$

where m is the mass of the electron and r is the radius of the orbit
The K.E. of the electron is the calculated as

$$K.E. = \frac{1}{2}mv^2 = \frac{e^2}{8\pi\varepsilon_0 r} \qquad \ldots\ldots (3.10)$$

The electrostatic potential for the electron is

$$P.E. = \frac{-e^2}{4\pi\varepsilon_0 r}$$

$$E_t = \frac{e^2}{\pi\varepsilon_0 r}\left(\frac{1}{8} - \frac{1}{4}\right)$$

$$= \frac{-e^2}{8\pi\varepsilon_0 r} \qquad \ldots\ldots\ldots\ldots (3.11)$$

The negative sign has an important physical meaning. It shows that the electron needs this amount of energy, E_t, to be set free from its nucleus. E_t is the binding energy of the electron to its nucleus and is sometimes known as the ionization energy. Furthermore, E_t is also the ground state energy of the atom i.e. the minimum energy that can be possessed by the atom. Experimental results show that the ionization or ground state energy, E_0 of hydrogen is 13.6 eV.

The minimum orbital radius is deduced as:

$$E_0 = \frac{e^2}{8\pi\varepsilon_0 r_0}$$

$$\therefore r_0 = 0.053\ nm$$

Thus, the model succeeded to give a size, r_0 comparable to that measured experimentally of the hydrogen atom. However, the eq.(3.11) shows that r_0 is inversely proportional to E_t which is negative. This shows that if the energy of the electron decreases due to electromagnetic irradiation, it leads to a decrease in the radius. Consequently, the atom will shrink, as radiation goes on, the electron will spiral and eventually fall into the nucleus. Of course such model contradicts the fact of atomic stability and matter doesn't shrink around us. The electromagnetic radiation frequency given off by the electron may be calculated by classical mechanics.

$$K.E. = \tfrac{1}{2} m \mathrm{v}^2 = \tfrac{1}{2} m \omega^2 r^2$$

$$\omega = \sqrt{\frac{2K.E.}{mr^2}} \qquad ....(3.12)$$

where v is the velocity of the electron rotating in the orbit of radius r.

From eq.(3.10), $K.E. = -E_t$, the frequency of the rotation, f=ω/2π, increases continuously as E_t decreases. Therefore for continuous emission, ω will increase continuously as well. Therefore, a continuous spectrum of radiation is emitted accompanied by decrease in energy. The continuous spectrum contradicts the discrete line spectra recorded for different materials.

3.5.2. Bohr's Model of the atom:

Bohr suggested some additional ideas besides classical ideas to describe the atom. These ideas were mainly inspired from the quantum hypothesis introduced by Planck and photon theory by Einstein .

The main **postulates**, that Bohr suggested for the hydrogen atom, and were proven to give satisfying results are:

i. The electron revolves around the nucleus in a certain circular orbit without radiating energy or else it spirals into the nucleus. The radiation occurs only when it jumps from one orbit to another of a different radius. This means that the electron exists in one of its discrete orbits having discrete energy value and cannot exist in between these orbits and hence cannot have except discrete energy values.

ii. The allowed orbits, known as stationary states, are those states for which the orbital angular momentum, L, of the electron is equal to an integral multiple of $h/2\pi$, or $\hbar$:

$$L = m\,v\,r = \mathbf{n}h/2\pi = \mathbf{n}\,\hbar \quad \ldots\ldots\ldots\ldots(3.13)$$

n is known as the principle quantum number.

iii. Whenever an electron jumps from an initial higher energy orbit, E_i to a lower energy orbit, E_f, an electromagnetic radiation quantum, or photon, of energy $h\nu$ is emitted so that:

$$h\nu = E_i - E_f \qquad \nu = \frac{E_i - E_f}{h} \qquad \ldots(3.14)$$

So the absorbed energies are as those equal to ΔE only so that the atom is put in one of its higher allowed stationary energy states.

iv. The velocity of the electron in a certain orbit, n, is obtained as:

$$v_n = \frac{nh}{2\pi mr}$$

$$\because \frac{-1}{2} mv^2 = \frac{-e^2}{8\pi\varepsilon_0 r}$$

$$\therefore \frac{1}{2m}\left(\frac{n\hbar}{r}\right)^2 = \frac{-e^2}{8\pi\varepsilon_0 r}$$

$$\therefore r_n = \left(\frac{n\hbar}{e}\right)^2 \frac{8\pi\varepsilon_0}{2m} = a_0 n^2 \qquad \ldots(3.15)$$

v. Only certain radii are allowed for the allowed states. The subscript, **n**, is added to the radius to imply that. a_0, is known as the Bohr radius. a_0 is the smallest radius that the hydrogen atom can have and it is equal to 0.053 nm

$$a_0 = 4\pi\varepsilon_o\hbar^2/me^2$$

$r_1 = a_0 = 0.053$nm, $r_2 = 4a_0 = 0.212$nm, $r_3 = 9a_0 = 0.477$nm and so on.

Substituting from eq.(3.13) in eq.(3.8) to obtain the corresponding energies of the electron in a hydrogen atom:

$$E_n = \frac{-e^2}{8\pi\varepsilon_0 r_n}$$

$$= \frac{-m}{2\hbar^2 n^2}\left(\frac{e^2}{4\pi\varepsilon_0}\right)^2$$

$$= -\frac{-E_0}{n^2}$$

$$\therefore E_0 = \frac{me^2}{8h^2\varepsilon_0} = 13.6eV \qquad ....(3.16)$$

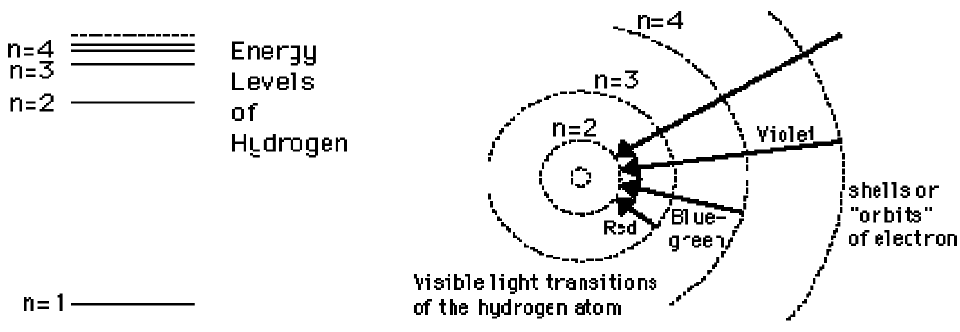
E_1=-E_0=-13.6eV, E_2=-E_0/4=-3.4eV, E_3=-E_0/9=-1.5eV and so on

The corresponding velocities may be derived as:

$$\mathrm{v}_n^2 = -\frac{2E_n}{m} = \frac{2E_0}{mn^2}$$

$$\mathrm{v}_n = \frac{1}{n}\frac{e^2}{4\pi\varepsilon_0\hbar} \qquad ...(3.17)$$

The allowed stationary levels are illustrated in fig (3.13). As the order, n, of the level increases, the atoms radius becomes larger and its energy increases and its velocity decreases. The electron possesses a larger amount of energy thus it is easier to be freed from the atom and the atom becomes an ion . That is the reason why the ground state energy is known as the ionization energy as well.



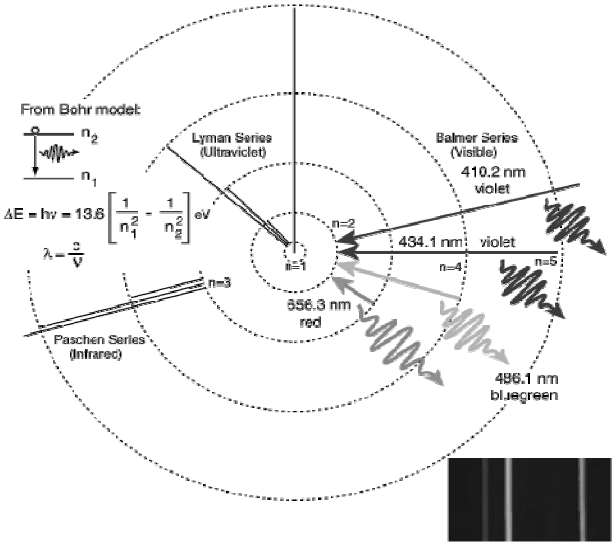
Fig(3.13)

Energy space representation of the energy levels in a hydrogen atom.

Above 0 e v the energy is continuous.

3.6 **Atomic Line spectrum for hydrogen:**

Energy is emitted or absorbed only when a transition between the different levels occur. In case of emission the initial energy is higher than the final energy and the atom loses energy in the form of electromagnetic radiation of frequency, *v*.



Fig(3.14)

Space representation of the first four orbits in a hydrogen atom.

According to Bohr's model: $hv=E_i-E_f$

$$\frac{hc}{\lambda} = -\frac{-E_0}{n_i^2} - \left(-\frac{-E_0}{n_f^2}\right) = E_0\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) \qquad ...(3.18)$$

The emitted wavelengths are given by: $\frac{1}{\lambda} = \frac{E_0}{hc}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$

The absorbed wavelengths are given by: $\frac{1}{\lambda} = \frac{E_0}{hc}\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right)$

The concept of **ground state** is more easily understood now. It is the minimum energy that the system can acquire. The excited states are all other higher energy states. Atoms in the excited state do not remain there for more than 10^{-8} sec. before they return to their normal ground state. Emission spectral lines are emitted due to this return. Frequencies or wavelengths emitted can be easily calculated from eq.(3.19). These calculations are exactly the same as those wavelengths found in the emission spectrum of hydrogen illustrated in fig. (3.10).

According to the mathematical deduction of Rydberg who worked years before Bohr, the main formula that governs the spectral lines of the Hydrogen atom is:

$$\frac{1}{\lambda} = R\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right) \qquad ....(3.19)$$

where **R** is Rydberg's constant for hydrogen = $1.097\times10^{7} m^{-1}$. The series shown in table(3.2), represent the formulae deduced mathematically to satisfy the emission wavelengths spectra recorded for Hydrogen. These series, recorded prior to the announcement of Bohr's model, are named after the scientists who recorded them. Lyman's series defines the group of wavelengths emitted by hydrogen that were found to correspond to final state of one ($n_f = 1$) and n= 2,3,4... . While Balmer's series corresponds to wavelengths generated if $n_f= 2$ and $n_i = 3,4,5$ Paschen series is generated if $n_f=3$ and $n_i= 4, 5,6$.

Table3.2. Different series recorded before Bohr introduced his model

Name	**Wavelength Range**	**Series Expression**
Lyman	Ultraviolet	$\frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right), n \geq 2$
Balmer	Near UV & Visible	$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right), n \geq 3$
Paschen	Infrared	$\frac{1}{\lambda} = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right), n \geq 4$
Bracket	Infrared	$\frac{1}{\lambda} = R\left(\frac{1}{4^2} - \frac{1}{n^2}\right), n \geq 5$
Pfund	Infrared	$\frac{1}{\lambda} = R\left(\frac{1}{5^2} - \frac{1}{n^2}\right), n \geq 6$

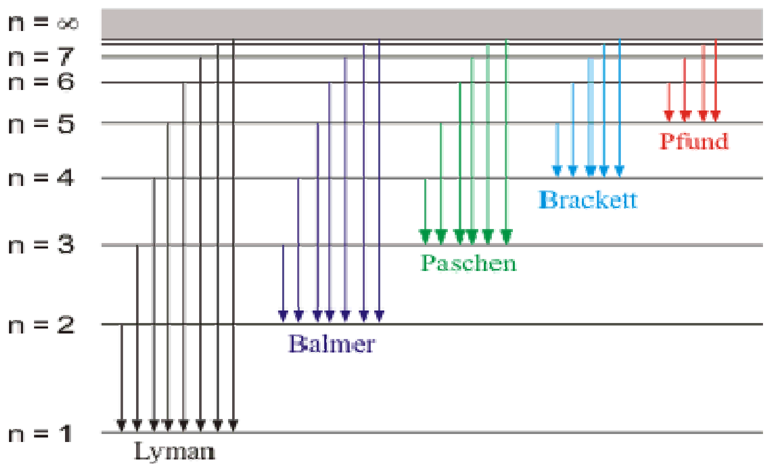
3.6.4.**Validity of the Bohr Model:**

i. Firstly, the value of the constant, R, coincides with the calculation of E_0/hc

ii. Secondly, the wavelengths recorded by experimental means, shown in Table(3.2) can be regenerated by the Bohr model eq.(3.18).

iii. The constants recorded experimentally for ground state and higher atomic states, e.g. E_n, r_n, v_n , …etc. can produced easily by the model.

iv. The orbital number, n, introduced by Bohr coincides with the principle quantum number deduced by solving the wave equation for the hydrogen atom.



Fig(3.14) Electromagnetic radiation is emitted from a hydrogen atom only when an electron makes transition from a higher energy level to lower one

Example3. 2

For a hydrogen atom, the principal quantum number is n =2.

a) Calculate the energies of stationary states.

b) Determine the wavelengths that are emitted from this atom.

Solution

$E_n=-E_0/n^2$ where n=1, 2

$E_0=13.6eV$ $E_1=-13.6eV$ & $E_2=13.6/2^2=-3.401eV$

$\Delta E=hc/\lambda= E_2 - E_1 = 1240(eV.nm) /\lambda(nm)=(-3.401-(-13.6))$ ev. $\lambda=124nm$

Conclusion:

i-The atomic spectrum really represents the identity of the material.
ii-The spectrum of the atoms lead us to produce a good idea about the atom components and how they behave.
iii-The atomic spectrum is helpful to explore far –non reachable planets and stars environments. The topic of atomic spectrum is developed motivated by the received light and radiation from different stars.
iv- There are a lot of applications based mainly on the absorption and emission spectrums of the atoms such as flourescent lamps, neon lamps, etc..

Chapter IV

Lasers

4.1 Introduction:

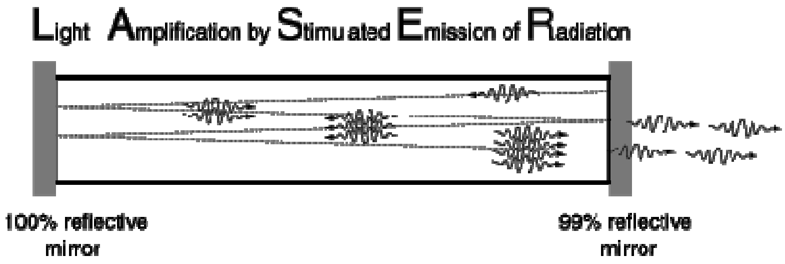
Laser stands for ‘light amplification by stimulated emission of radiation’. The lasers first appeared in 1960 when Maiman announced the invention of the first ruby laser. Also, Javan, Benett and Herriott announced in the same year that they made the first helium-neon laser. Later in the year 1962 the first semi-conductor laser was introduced.

The Laser beam is extremely monochromatic of extremely narrow waveband. Its interference fringes can be obtained with long path differences. The beam is almost parallel with very small angular spread.

It is not allowed to fall on the eye as it focuses on a small spot causing damage to the retina. This is because of its parallelism. It is not allowed to be reflected to the eye from a glassy surface as well. On the other hand, this property, of parallelism, is highly applicable in surgery especially eye cornea and short sightedness operations. The laser beam is used as a clean and sharp method of cutting very narrow and sensitive parts of the lumen cells.

4.2 Characteristics of Laser Light:

Lasers are produced because of the way light interacts with electrons. Electrons exist at specific energy levels or states characteristic of their particular atoms or molecules. The energy levels can be imagined as rings or orbits around a nucleus as shown in fig.(3.14). Electrons in outer rings are at higher energy levels than those in inner rings. Electrons can be pumped up to higher energy levels by the injection of energy, for example, by a flash of light. When an electron drops from an outer to an inner level, "excess" energy is given off as light. The wavelength or color of the emitted light is precisely related to the amount of energy released. Depending on the particular lasing material being used, specific wavelengths of light are absorbed (to energize or excite the electrons) and specific wavelengths are emitted (when the electrons fall back to their initial level).



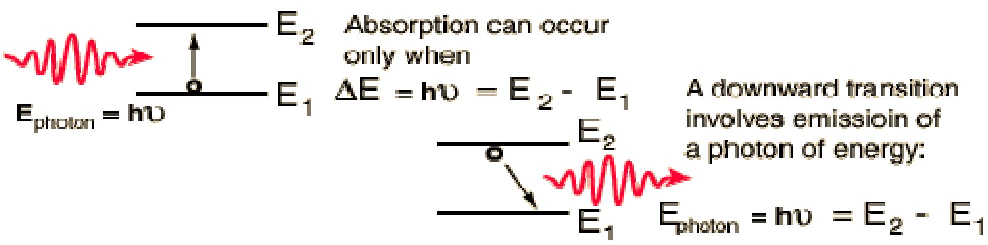
Fig(4.1)

Laser tube

4.3. The Principle of Laser Action

If an atom or a molecule interacts with or absorbs a photon it is said to be in an excited state. According to the Bohr theory, any atom has a set of possible energy levels, each level corresponds a particular electronic configuration.

Atomic transitions, which emit or absorb visible light, are generally electronic transitions and are pictured in terms of electron jumps between quantized atomic energy levels. We consider an atom having only two possible energy states, an upper state, E_2 and a lower one, E_1 are shown in the following figure:



Fig(4.2)

Spontaneous transition

If an atom in the upper state makes a transition to a lower state then the energy difference between to two levels (E_2-E_1) is released in the form of a photon. According to Plank's theory the energy possessed by a photon is proportional to its frequency.

$$v = (E_2 - E_1)/h \qquad ......(4.1)$$

If an atom is initially in the lower state E_1 and it makes a transition to the upper state E_2 then it absorbs a photon such that hv equals the value,

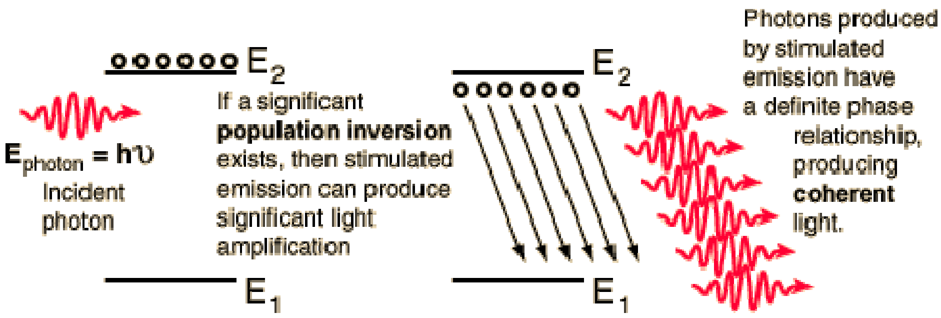
$$\Delta E = E_2 - E_1.$$

In 1917 Einstein discovered that there are two possible types of emission:

*An atom moves to a lower state randomly causing spontaneous emission or moves to an upper state causing spontaneous absorption as shown in fig. (4.2)

* A photon of energy equal to the energy difference ΔE, interacting with an atom in the higher state will cause it to change to the lower state creating a second photon.

This process is known as stimulated emission and is illustrated in fig. (4.2). The stimulated emission of light is the crucial quantum process necessary for the operation of a laser.



Fig(4.3)

Stimulated transition

Note that the produced photons are of precisely the same frequency as the incident photons ($v = \Delta E/h$) and they are in phase with them thus producing what is known as a coherent wave. On the contrary photons produced by spontaneous emission are not in phase and are known as incoherent.

4.4 Main properties of Lasers:

I.Coherence:

Coherence is one of the unique properties of laser light. It arises from the stimulated emission process which provides the amplification. Since a common stimulus triggers the emission events which provide the amplified light, the emitted photons are "in step" and have a definite phase relation to each other. This coherence is described in terms of temporal coherence and spatial coherence, both of which are important in producing the interference which is used to produce holograms.

Ordinary light is not coherent because it comes from independent atoms which emit on time scales of about 10^{-8} seconds. Different parts of the laser beam are related to each other in phase. These phase relationships are maintained over long enough time so that interference effects may be seen or recorded photographically. This coherence property is what makes holograms possible.

II. Monochromatic:

The light from a laser typically comes from one atomic transition with a single precise wavelength. So the laser light has a single spectral color and is almost the purest monochromatic light available.

That being said, however, the laser light is not exactly monochromatic. The spectral emission line from which it originates does have a finite width, if only from the Doppler effect of the moving atoms or molecules from which it comes. Since the wavelength of the light is extremely small compared to the size of the laser cavities used, then within that tiny spectral bandwidth of the emission lines are many resonant modes of the laser cavity.

III. **Collimated:**

The high degree of collimation arises from the fact that the cavity of the laser has very nearly parallel front and back mirrors which constrain the final laser beam to a path which is perpendicular to those mirrors. The back mirror is made almost perfectly reflecting while the front mirror is about 99% reflecting, letting out about 1% of the beam. This 1% is the output beam which you see. But the light has passed back and forth between the mirrors many times in order to gain intensity by the stimulated emission of more photons at the same wavelength. If the light is the slightest bit off axis, it will be lost from the beam.

Because of bouncing back between mirrored ends of a laser cavity, those paths which sustain amplification must pass between the mirrors many times and be very nearly perpendicular to the mirrors. As a result, laser beams are very narrow and do not spread very much.

The highly collimated nature of the laser beam contributes both to its danger and to its usefulness. You should never look directly into a laser beam, because the highly parallel beams can focus to an almost microscopic dot on the retina of your eye, causing almost instant damage to the retina. On the other hand, this capacity for sharp focusing contributes to the both the medical applications and the industrial applications of the laser. In medicine it is used as a sharp scalpel and in industry as a fast, powerful and computer-controllable cutting tool.

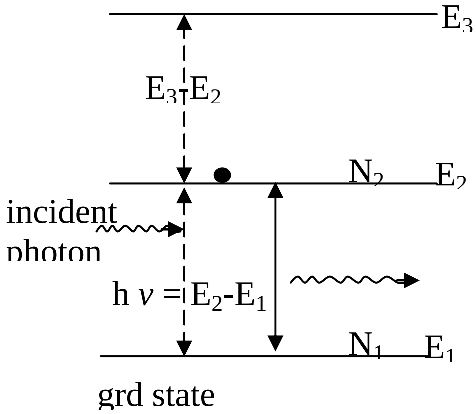
4.5 Population Inversion:

The achievement of a significant population inversion in atomic or molecular energy states is a precondition for laser action. Electrons will normally reside in the lowest available energy state. They can be elevated to excited states by absorption, but no significant collection of electrons can be accumulated by absorption alone since both spontaneous emission and stimulated emission will bring them back down.

A population inversion cannot be achieved with just two levels because the probability for absorption and for spontaneous emission is exactly the same, as

shown by Einstein and expressed in the Einstein A and B coefficients. The lifetime of a typical excited state is about 10^{-8} seconds, so in practical terms, the electrons drop back down by photon emission about as fast as you can pump them up to the upper level. The case of the helium-neon laser illustrates one of the ways of achieving the necessary population inversion. Consider a three energy level system as shown in fig.(4.3) under effect of an incident photon interacting with an atom in the intermediate energy level. The probability that the atom absorbs the photon and rises to E_3 is equal to the probability of its emitting another photon and moving to E_1.

In stimulated emission process, it is required that the atom or molecule moves to the lower state. This is more likely to occur only if a large population of atoms is present in the higher state E_2. The lower population in E_1 stimulates the atom to release a photon.



Fig(4.4)

A three level system

According to Plank's theory the energy possessed by a photon is proportional to its frequency. If an atom is initially in the lower state E and it makes a transition to the upper state E then it absorbs a photon such that hv equals the value the produced photons are of precisely the same frequency as the incident photons ($\nu = \Delta E/h$) and they are in phase with them producing what is known as a coherent wave.

On the contrary photons produced by spontaneous emission are not in phase and produce incoherent wave Consider a three energy level system as shown in fig.(4.4)

An incident photon interacts with an atom in the intermediate energy level. The probability that the atom absorbs the photon and rises to E_3 is less than the probability of its emitting another photon and moving to E_1. In stimulated emission process, it is required that the atom or molecule moves to the lower state. This is more likely to occur only if a large population of atoms is present in the higher state E_3 . The lower population in E_1 stimulates the atom to release a photon and move downwards rather than upwards.

Under conditions of thermal equilibrium, the population of energy levels obey the Boltzman distribution:

$$N_2 = N_1 \, e^{-(E_2 - E_1)/kT} \qquad ....(4.2)$$

where k is Boltzman's constant, T is the absolute temperature in kelvins, N_2 and N_1 are number of atoms or molecules present in consecutive energy levels.

For population inversion and thus stimulated emission to be achieved, $N_2 > N_1$, the temp T must be negative. So lasing doesn't occur in thermal equilibrium systems. That's why population inversion condition is sometimes called the *negative temperature* case though it can never be achieved by reducing temperature. It is achieved by manipulating a non-thermal equilibrium system

4.6 **Designing Laser tubes**

In contrast to an ordinary light source, a laser produces a narrow beam of very bright light. Laser light is "coherent," which means that all of a laser light rays have the same wavelength and are in synchronism. To implement the lasing conditions:

i. High-voltage electricity is supplied to cause the exciting of some atoms to higher energy levels.
ii. At a specific energy level, some atoms emit photons in all directions. Photons from one atom stimulate emission of photons from other atoms and the light intensity is rapidly amplified
iii. Mirrors at each end reflect the photons back and forth, continuing this process of stimulated emission and amplification.

Once an atom is in an excited state, there's a probability that the atom will jump back to the lower energy level emitting a photon, by spontaneous emission. It occurs without requiring an event to trigger the transition. The atom remains in an excited state for only about 10^{-8}s. Stimulated emission occurs if the atom is in an excited metastable state. Its lifetime is about 10^{-5}s. Population inversion described earlier increases the probability of photon stimulated emission above that of photon stimulated absorption. An acronym for light amplification by stimulated emission is created. The amplification corresponds to a build up of photons in the system as the result of a chain reaction of events.

Three conditions are essential to achieve laser action:

i) The system must be in a state of population inversion.

ii) The excited state of the system must be a metastable state so that stimulated emission occurs before spontaneous emission.

iii) The emitted photons must be confined in the system long enough to stimulate further emission from other excited atoms. This confinement is achieved by the use of high reflectivity mirrors at the ends of the active material.

4.6.1 Heliom-Neon laser tube:

The most common gas laser, the helium-neon laser is usually constructed to operate in the red at 632.8 nm. It can also be constructed to produce laser action in the green at 543.5 nm and in the infrared at 1523 nm. An unfocused 1-mW HeNe laser has a brightness equal to sunshine on a clear day (0.1 watt/cm^2) and is just as dangerous to stare at directly.

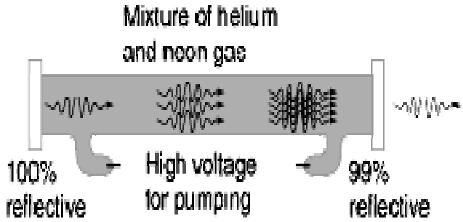


Fig.(4.4)

A mixture of helium and neon is confined in a sealed glass tube. A schematic diagram shows its design in fig (4.4).

The tube contains atoms that represent the active medium. An external source of energy pumps the atoms to the excited state. The parallel end mirrors confine the photons to the tube but mirror 2 is slightly transparent. An oscillator connected to the tube causes electrons to sweep through it, colliding with the gas atoms and raising the neon atoms jump to the excited metastable them to the excited states. As a result stable E_2 through this process. Fig.(4.5) shows, excited neon atoms due to collision with electrons and excited helium atoms. Stimulated emission occurs as the neon atoms make a transition to state E_1 and neighboring excited atoms are stimulated. This results in the production of coherent light at a wavelength of 632.8nm.

The main function of helium is to excite the neon atoms by collision. It is advantageous to increase the density of helium atoms with respect to the neon atoms. This is achieved by filling the laser tube with helium at a pressure of 1 torr and neon at a pressure of 0.1 torr. The helium gas in the laser tube provides the pumping medium to attain the necessary *population inversion* for laser action. One of the excited levels of helium at 20.61 eV is very close to a level in neon at 20.66 eV, so close in fact that upon collision of a helium and a neon atom, the energy can be transferred from the helium to the neon atom.

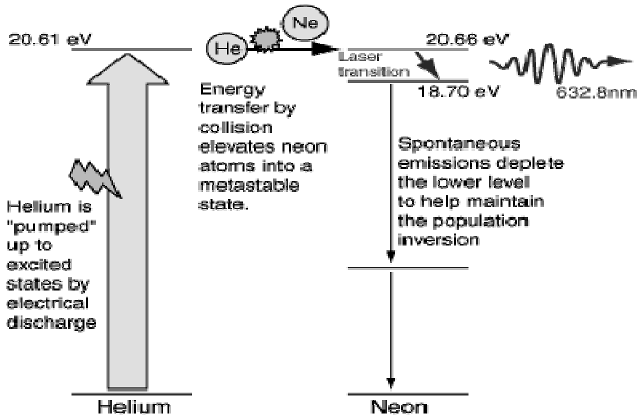
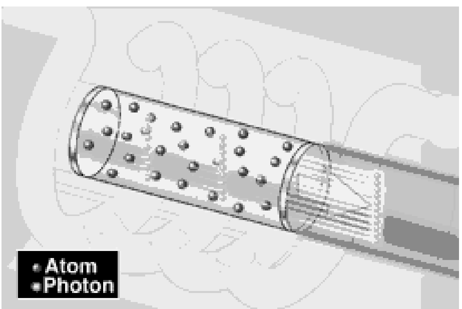


Fig.(4.5) Energy level diagram for a neon atom in a helium-neon laser.

4.6.2. The Ruby Laser



The ruby laser was the first laser invented in 1960. The ruby crystal consists of an aluminum oxide crystal in which some of the aluminum atoms have been replaced with chromium ions(Cr^{+++}). A small concentration (0.01%-l%) of chromium ions, in a lattice of crystalline aluminum oxide gives ruby its characteristic red color and is responsible for the lasing behavior of the crystal. Chromium ions absorb green and blue light and emit or reflect only red light.

The ruby laser is an example of a three level system shown in fig. (3.18). An intense flash of white light is used to excite the chromium ions from the ground state to upper state. The upper states actually consist of a large number of narrow spaced energy levels forming an energy band. The excited atoms then drop back from the band of the upper state to a middle state, which is considered as the metastable state. This transition is not accompanied by photon emission but it transfers energy to the surrounding crystal lattice directly. This energy heats up the ruby rod and the process is known as a non-radioactive transition.

Once an atom reaches the middle state it spends an unusually long time there about 10^{-5}s compared to the usual 10^{-8}s of any other state. Thus a population inversion is achieved, and the ground state is more depleted than the middle state. Once a few photons are emitted by spontaneous emission from the middle state to the ground state, an avalanche of photons will build up by *stimulated emission.* This goes on till

the number of ions in the middle state is so reduced that population inversion no longer exists and the laser source is worn out.

For a ruby laser, a crystal of ruby is formed into a cylinder. A fully reflecting mirror is placed on one end and a partially reflecting mirror on the other. A high-intensity lamp is spiraled around the ruby cylinder to provide a flash of white light that triggers the laser action. The green and blue wavelengths in the flash excite electrons in the chromium atoms to a higher energy level. Upon returning to their normal state, the electrons emit their characteristic ruby-red light. The mirrors reflect some of this light back and forth inside the ruby crystal, stimulating other excited chromium atoms to produce more red light, until the light pulse builds up to high power and drains the energy stored in the crystal.

The laser flash that escapes through the partially reflecting mirror lasts for only about 300 millionths of a second but very intense. Early lasers could produce peak powers of some ten thousand watts. Modern lasers can produce pulses that are billions of times more powerful.

4.6.3 Argon Laser

The argon ion laser is operated as a continuous gas laser at about 25 different wavelengths in the visible between 408.9 and 686.1nm, but is best known for its most efficient transitions in the green at 488 nm and 514.5 nm. This output is produced in a hot plasma and takes extremely high power, typically 9 to 12 kW, so these are large and expensive devices

4.6.4 Carbon Dioxide Laser

The carbon dioxide gas laser is capable of continuous output powers above 10 kw. It is also capable of extremely high power pulse operation. It exhibits laser action at several infrared frequencies but none in the visible. Operating in a manner similar to the helium-neon laser, it employs an electric discharge for pumping, using a percentage of nitrogen gas as a pumping gas.

The CO_2 laser is the most efficient laser, capable of operating at more than 30% efficiency. The carbon dioxide laser finds many applications in industry, particularly for welding and cutting.

In CO_2 lasers, an ionized mixture of helium, nitrogen and carbon dioxide is used for the generation of invisible infrared light with a wavelength around 10 µm. Free electrons, being always present in a considerable concentration in ionized gases, are accelerated by an electrical field to cause vibrations of the nitrogen molecules due to collisions and the latter pass over this energy to the CO_2 molecules. The CO_2

molecules that start to carry out vibrations, whereas the central carbon atom remains resting and the two oxygen atoms move synchronously to the right or to the left Fig.(3.22). If now an infrared light wave of appropriate wavelength falls on these vibrating molecules, the electrical field strength of the wave polarizes and second decelerates then the atoms, what causes them to deliberate some part of their vibration energy, thus amplifying the light wave. The higher the gas speed, the higher the output power can be, whereas modern carbon dioxide lasers yield beam powers up to 10 kW CW out of a length of the active medium of 1m, so they are practically the strongest lasers, that are available nowadays.

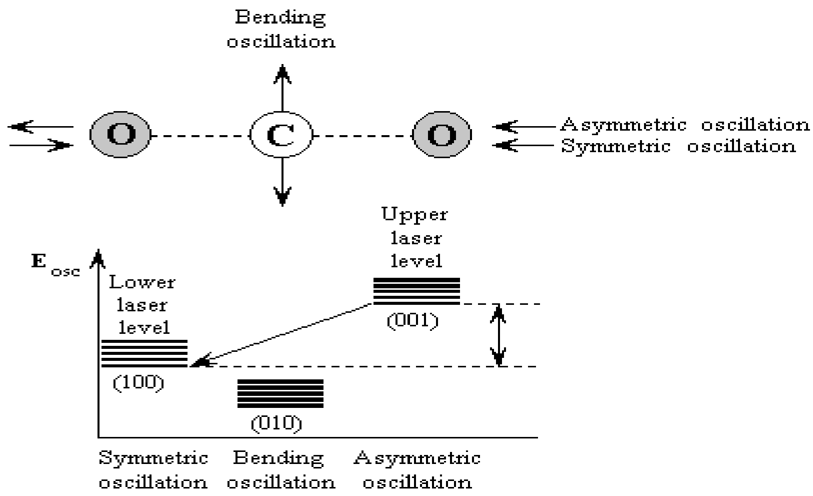


Fig.4.6 Vibrations of the carbon dioxide molecules

It is used in the treatment of infected wounds, scar tissue, warts, and other skin disorders. Unlike the other lasers, this laser's energy is absorbed by fluid which is contained in all human tissue.

A more recent development is the ultra pulse carbon dioxide laser whose unique technology produces a beam which markedly reduces the risk of injury such as burns to the skin.

4.6.5. Excimer lasers

Excimer lasers use noble gases, as for instance xenon, that are brought to excited states. In ionized gases due to collisions with energetic electrons to form artificial molecules with halogen atoms, as for instance chlorine. These artificial molecules called 'excimers' are of course unstable and dissect after the excited atom has returned to the ground state, thus releasing their binding energy. Since the latter energy is in the order of eV, ultraviolet light - precisely with a wavelength of $\lambda = 0.3\ \mu m$ in the case of xenon chloride - is deliberated.

The light emission due to the breaking up of excimers can also be stimulated by an incoming lightwave, thus leading to light amplification.

The stimulating action of an incoming lightwave occurs when an electron, that is on a higher energy level i.e in a larger orbit for the excited atom, can become

decelerated due to the electrical field strength of the light wave under the condition of a resonance between the frequency of the electron rotation and the light wave. Thus going back to its initial energy level and a smaller orbit, whereas the deliberated electron energy is used to amplify the stimulating lightwave.

4.7. Applications of lasers:

4.7.1 General laser applications:

Since the development of the first laser in 1960, there has been a tremendous growth of laser technology. Lasers are now available covering wavelengths in the infrared, visible, and ultraviolet regions.

- Applications include astronomical and geophysical purposes, to measure precisely the distance from various points on the surface of the earth to a point on the moon's surface.
- It is also used to decode the digital information on the compact audio laser disc, the so called **CD**. On which one can store enormous information about 1 gigabyte.
- In the field of energy production, powerful lasers are used to cause thermonuclear fusion of heavy hydrogen, thus producing energy.
- Medical applications of lasers utilize the fact that different laser wavelengths can be absorbed in specific biological tissues. Ex. Eye operations and liver operations… which will be discussed later

4.7.2 .Biological applications:

Lasers produce high radiation power. Therefore it is important to study the effect of the laser beam on biological tissues. As with any type of surgery, laser surgery is not without risks. Possible problems include incomplete treatment of the problem, pain, infections, bleeding, scarring, and skin color changes.

The laser beam is so small and precise, it enables physicians to safely treat specific tissue without injuring surrounding tissue. A wavelength of 900nm is considered highly penetrative to the human tissue.

Some Major surgical applications:

1. Surgical welding of detached retinas, is one of the most famous and important laser applications in medicine. A serious side effect of diabetes is nero-vascularization, the proliferation of weak blood vessels, which often leak blood. Vision deterioration, occurring as a result, is known as diabetic retinopathy. A green light from an argon ion laser is directed through the clear eye lens and eye fluid, focus on the retina edges and photocoagulate the leaky vessels, as shown in Fig.(4.7)

2. Near sightedness is corrected by using laser to reshape the cornea, changing its focal length and reducing the need for eyeglasses.

3. Glaucoma is a widely spread eye condition characterized by a high fluid pressure -in the eye which leads to destruction of the optic nerve. A process known as irridectomy in which a laser beam is used to burn open a tiny hole in a clogged membrane, relieving the destructive pressure. Its highly concentrated energy over microscopic dimensions, can give energy density of 1012 times that in a flame of a typical cutting torch

4.Lasers are used widely in microscopic cytology. For these purposes the optical axis of the microscope objective can be directed and focused. It is important in medical research to isolate and collect unusual cells for study and growth. These specific cells can be tagged with fluorescent dyes.

5. The laser beams can also be used for diagnostic purposes as a source for flash and tissue photography, of the spectral biochemical analysis of pathogenic cuts

6. Laser light at 10 µm from a carbon dioxide laser can cut through muscle tissue, primarily by vaporizing the water contained in cellular material. Laser power of about 100 w is required in this technique. The advantage of the laser knife over conventional methods is that laser radiation cuts tissue and coagulates blood at the same time, leading to reduction in blood loss

7. A laser beam can be trapped in fine glass-fiber light guides (endoscopes) by means of total internal reflection. The light fibers can thus be introduced through natural internal organs, and directed to specific interior body orifices, conducted around locations, eliminating need for invasive surgery. Bleeding in the gastrointestinal tract can be optically cauterized by fiber-optic endoscopes inserted through the mouth.

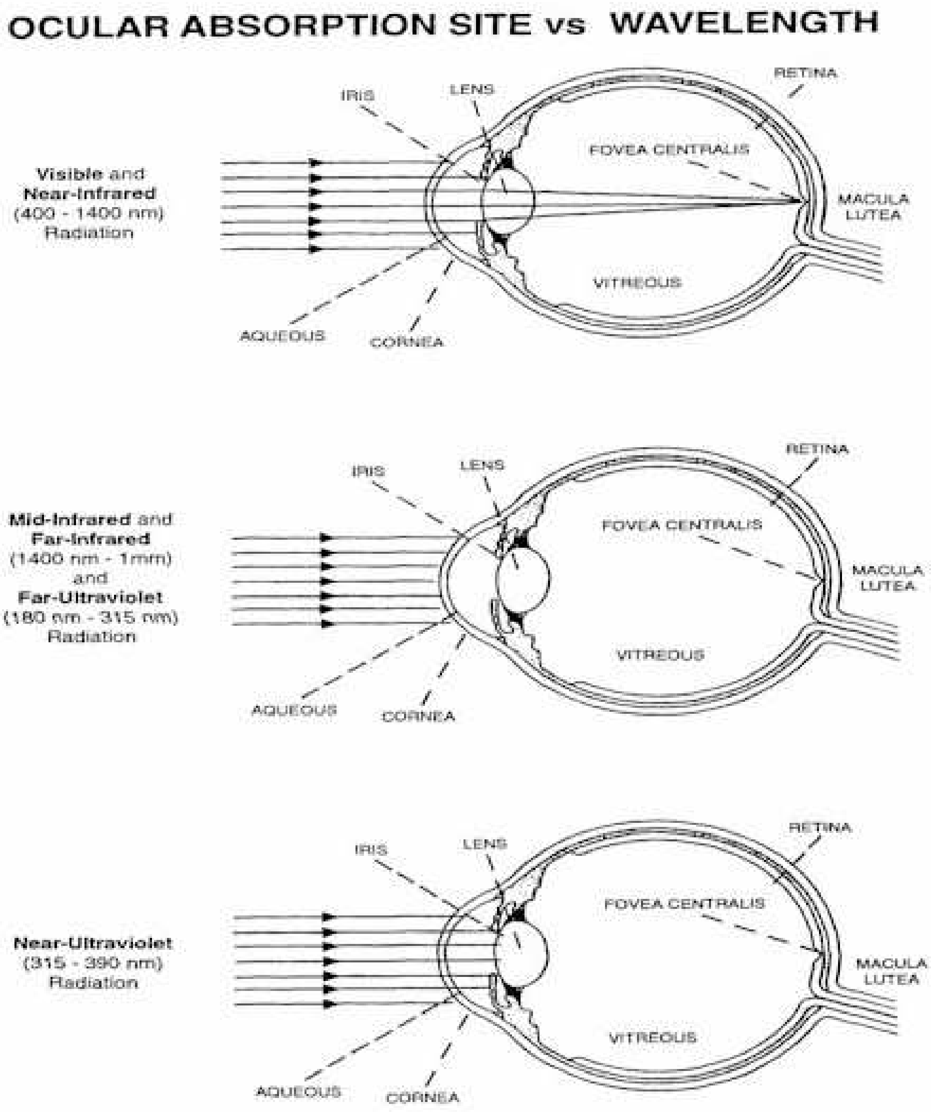


Fig.(4.7)

Arthroscopic laser systems cut tissue deeply enough and quickly. The cut edges are exact, not ragged. Thermic damage and other side effects are kept to a minimum. There should be no carbonization. The system must be easy to use with a simple laser beam guidance system. Because only a few biological tissues are treated and only certain procedures are used in orthopedic surgery, just a few laser systems out of the many available systems are acceptable for orthopedic procedures. These are listed according to increasing wavelength:

157 nm to 351 → Excimer laser
1064, 1320 and 1444 nm →Neody nmm: YAG laser

2100 nm →Holmium: YAG laser
2900 nm →Erbium: YAG laser
10600 nm →CO_2 LASER

Table 4.1 LASER PARAMETERS

Type	**HeNe**	**Argon**	**Ruby**	**Ruby**	**Nd-YAG**
	Gas	Gas	Free-running solid state	Q-switched solid state	Q-switched solid state
Power or Energy	5 mW	1.5 W	1 J	50 mJ	250 mJ
Wavelength	632.8 nm	514.5 nm	694.3 nm	694.3 nm	1064 nm
Pulse duration	Cw	cw	350 µs (FR)	30 ns (QS)	10 ns (QS)
Divergence (full angle)	1 mrad	1 mrad	5 mrad	5 mrad	5 mrad
Linewidth	1.5 GHz	1 GHz	330 GHz	330 GHz	180 GHz
Spontaneous lifetime	100 ns		3 ms	3 ms	550 µs
Refractive index	1	1	1.5	1.5	1.82
Beam diam	0.8 mm	1 mm	10 mm	5 mm	5 mm

4.7 The Benefits of Laser Surgery

1. High Precision: In conventional surgery, it is often necessary to remove healthy tissue along with diseased tissue. The laser, however, is capable of isolating and removing targeted cells without affecting the healthy cells surrounding them.

2. **Low Risk of Infection**: The risk of infection is reduced with laser surgery because only the beam of light comes in contact with the tissue. In addition, bacteria and viruses are vaporized along with body cells.

3. **Less Bleeding, less Swelling, less Pain**: Because the heating effect of the lasers' energy cauterizes or seals small blood vessels, there is less bleeding and swelling. There is less pain connected with the surgery because the beam seals nerve endings.

4. **Need for General Anesthesia Lessened**: The use of laser surgery has significantly reduced the need for general anesthesia, thus reducing the risk of complications connected with it.

The advantages of a laser system for knee arthroscopy originate in the smallness of its instruments. It remains to be seen if this causes improvement of long term results in comparison to the larger mechanical instruments